Special Constructional Design Features of Cold and Hot Neutron Source and Confirmation/Verification during Commissioning of the Hot and Cold Neutron Source at the FRM-II

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Abstract

During the year 2004 the new research reactor FRM-II of the Technical University of Munich was successfully tested in regards of cold an hot commissioning.
Two major FRM-II component for producing cold and hot neutrons for many different experiments are the cold neutron source (cns) and the hot neutron source (hns).
Within the design of both sources the following important design and safety items were investigated

- barrier and safety concept
- load cases and transient behaviour
- temperature distribution
- material investigation
- manufacturing and installation
- operational conditions
- maintenance concept
- pressure protection

In 2003 and early 2004 all auxiliary systems (cooling machine, metal hydride deuterium storage system, vacuum system) of the cns have been tested successfully during the cold commissioning phase.
In the same time all auxiliary systems of the hns (helium protection gas system, nitrogen system and inert gas system) have been tested also successfully.
From March 2004 to October 2004, the cns and hns was tested together with the FRM-II reactor at different nuclear power steps (0 – 20 MWatt).
During the commissioning of the cns and hns the mentioned constructional design features were tested and measured.
Beside the system I&C devices additional thermocouples were installed during the commissioning.
Design variation takes place with additional material investigations.
All tests within the cold and hot commissioning shows that for both sources the special constructional design requirements can be confirmed and verified.

1. Barrier and safety concept

The main technical data abd the safety concept of the HNS and CNS are shown in table 1 and 2. During the licensing process approval and the cold and hot commissioning phase with the results these safety requirements were checked also from independent experts.

Table 1:
Technical data CNS:
-14 l liquid deuterium (boiling liquid)
- cooling power ~ 4.7 kW at 25 K
- metal hydride storage system
- buffer tank for deuterium gas
- Integrated condenser
- Cooling of D_2 with thermo siphon
- Closed cycle Helium cooling machine
-He compressor 500 kW electrical power
- Fluence $n_{fast} = 5 \times 10^{21}$ n/cm^2
Safety concept CNS:
-Two barrier system for the deuterium
- Outer barrier withstand explosion pressure of 13 bar
- Integration of CNS control system within the reactor safety control system
- Activity control system (Tritium) for the exhaust gas
- Important parts of the CNS withstand earth quake and air plane crash
- Vacuum chamber of CNS is basic safe (leak before rupture criteria)
- Design for EOL of 30 years

Table 2:
Technical data HNS:
-Graphit temperature 2600°C
- $E_{thermal} = 68$ MJ
- $E_{Graphit} = 630$ MJ
- Fluence $n_{fast} = 5 \times 10^{21}$ n/cm^2
Safety concept HNS:
-Two barrier system for hot graphite
- Integration of HNS control system within the reactor safety control system
- Important parts of the HNS withstand earth quake and air plane crash
- Basic safety concept for inner and outer vessel
- Leak before break concept
- Design for EOL of 30 years

2. Load cases and transient behaviour

All load cases of the CNS and HNS are specified in the system desription and the technical specifications.
An overview of the load cases of the reactor shows and the load cases for the CNS shows /2/

Whilst the HNS has no relevant pressure and temperatures load cases, the CNS has load cases by handling the cold D2 up to 28 K from the storage vessels to the moderator vessel. These load cases were calculated during the design. Figure 1 shows the mass flow of D2 transfer to the buffer tank. Fig.2 shows the nodal configuration from the inpile part to the buffer tank. Fig. 3 shows the D2 temperatures and fig. 4 to fig.5 the temperature of the piping systems. The systems were designed to –196 °C.

Figure 1:Mass flow of D2 at transfer to the buffer tank

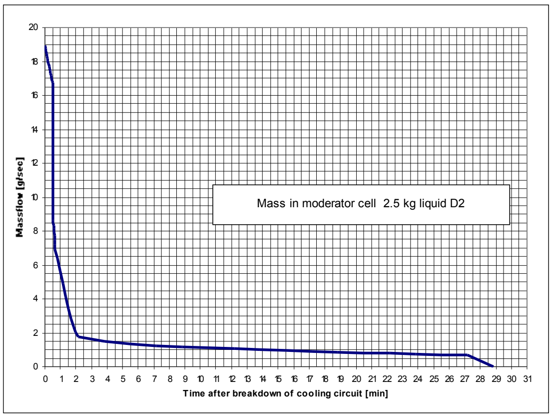


Figure 2: Nodal arrangment

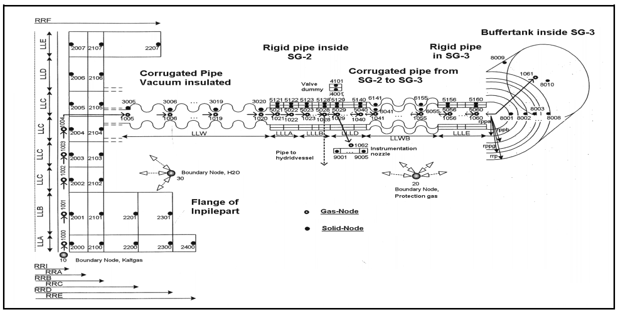


Figure3 :D2 temperature at transfer to the buffer tank

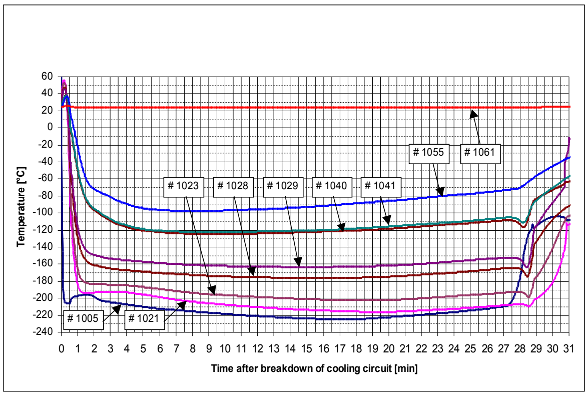


Figure 4:Temperatur of piping system
Mass flow D2 = 19,0 g/s

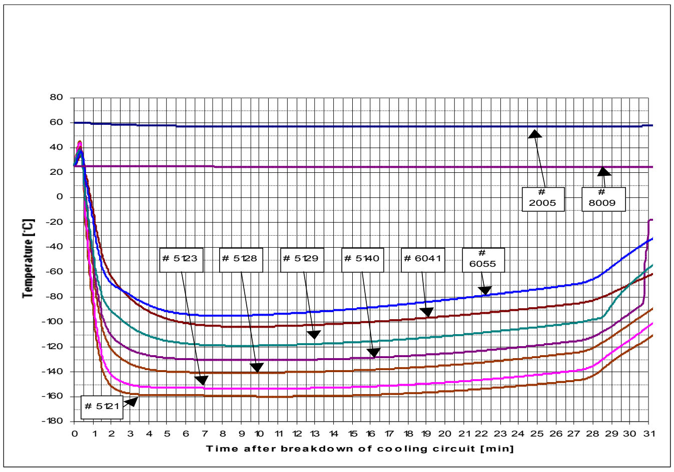
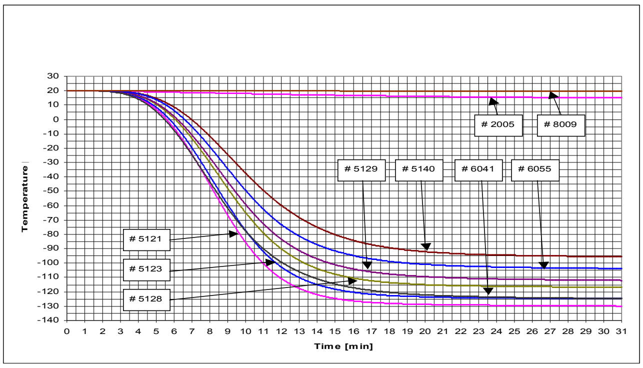


Figure 5: Temperature of piping system
Mass flow D2 = 1,344 g/s



During the commissioning phase Temporary measurement point were fixed at the piping system to the line to the buffer tank. Fig. 6 shows the local arrangement of the measuring places and figure 7 shows the results of the measurements. All results were acceptable and below the design values.

Figure 6: CNS Temporary temperature measurements during the commissioning phase

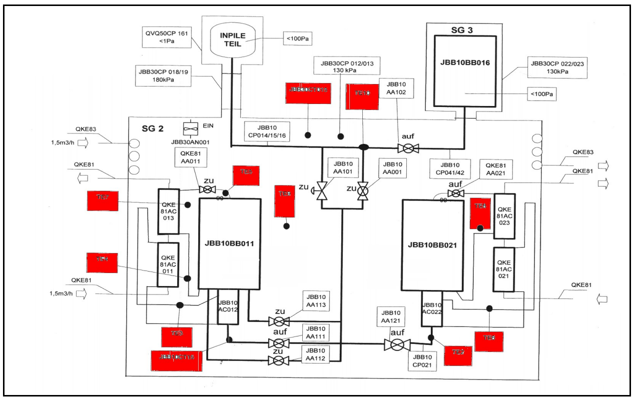


Figure 7: Results of measurements during the commissioning

•Storage of D2 at loss of cooling

-Power 9,5 MW TE 10 = -4 °C < -196 °C
- Power 20 MW TE 10 = - 10°C<-196°C

•Storage of D2 under breaking the vacuum area and flooding with neon

- Power 20 MW TE 10 = -45 °C <-196°C

2. Temperature distribution

Important temperature distribution are at the HNS with the graphite block inside of the inner vessel and the insulation. During the design the temperature distribution of the inner vessel and the outer vessel were calculated. Additionally the noise thermometer of the inner vessel were calculated. The design results are shown in figure 8 to figure10 .

Figure8 : Inner Vessel of the HNS

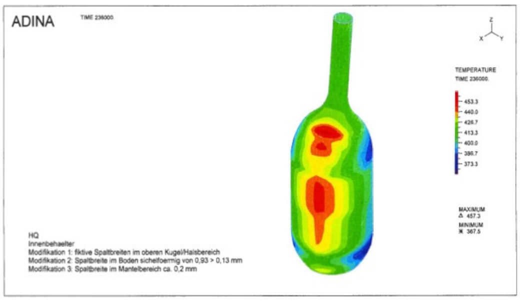


Figure 9: Outer vessel of the HNS

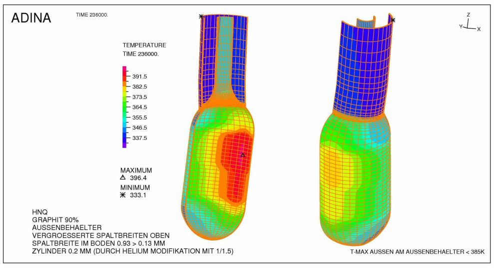
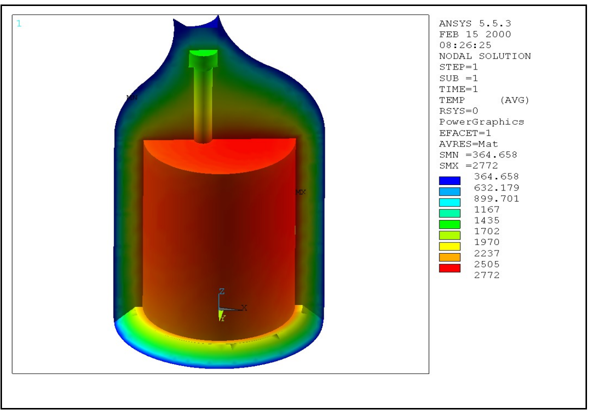
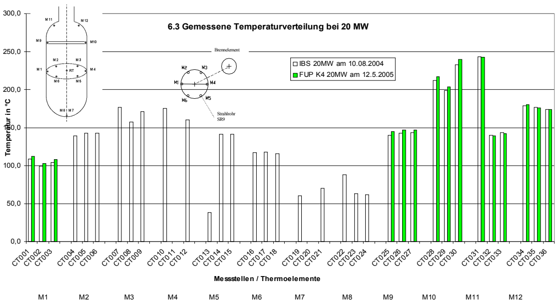


Figure 10: HNS with noise thermometer



During all hot commissioning steps between o and 20 MW the temperature distribution were measured with 37 thermocouples, the results are presented in the following fig. 11.

Figure 11: Measured temperature distribution



The results show that the expected temperature of 150°C of the inner vessel was increased up to temperatures to 240°C. The reason of this increase was variation of the gap between the inner and outer vessel.

4. Manufacturing and Installation

The leak tightness of the components and the systems are one of the major features for the HNS and CNS. During manufacturing and installation the inpile part and the connecting systems were pressure and leak tightness tested. The leakage rate was 10-8 mbarl/s or 10-6 mbarl/s. CNS and HNS fulfil the requirements. For the moderator vessel bursting tests and cold shock tests were carried out with acceptable results.

5. Operational conditions

The operational conditions of the HNS are steady state conditions. For the CNS different operational conditions are necessary for the cooling down of the D2, the warming up phase and the load cases loss of cooling and the fast storage load case to bring the system into a safe status.
All system part parts are visualized on the screen on the local panel and at the reactor control board.

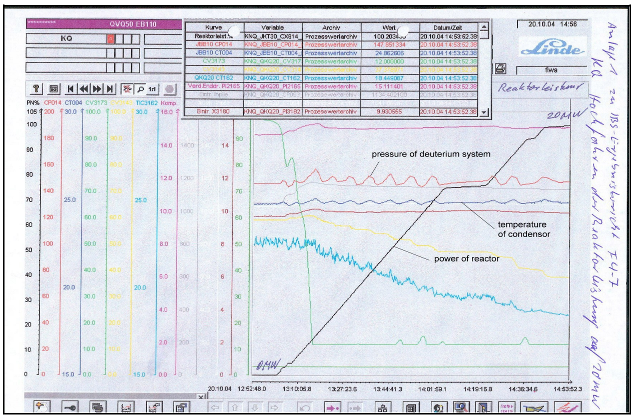
The system operational behaviour of the load cases

- reactor power increase
- fast reactor shut down are

presented in figure 12 and 13.

The figure 12 shows the constant power increase and the temperature of the condenser and the pressure in the deuterium system are controlled well. The figure 13 shows the fast rector shut down in ca. 10 sec. Caused of the reactor shut down the D2 pressure decrease in the first and the control system of the reactor /3/.

Figure 12 : Power increase of the reactor



Kurve	Variable	Archiv	Wert	Datum/Zeit
Reaktorleist.%	KNQ_JKT30_CX814_	Prozesswertarchiv	100.2034	20.10.04 14:53:52.38
JBB10 CP014	KNQ_JBB10_CP014_	Prozesswertarchiv	147.851334	20.10.04 14:53:52.38
JBB10 CT004	KNQ_JBB10_CT004_	Prozesswertarchiv	24.862606	20.10.04 14:53:52.38
CV3173	KNQ_QKQ20_CV317	Prozesswertarchiv	12.000000	20.10.04 14:53:52.38
CV3143	KNQ_QKQ20_CV314	Prozesswertarchiv	37.378971	20.10.04 14:53:52.38
QKQ20 CT162	KNQ_QKQ20_CT162_	Prozesswertarchiv	18.449087	20.10.04 14:53:52.38
Verd.Enddr. PI2165	KNQ_QKQ20_PI2165	Prozesswertarchiv	15.111401	20.10.04 14:53:52.38
Eintr. Inpile	KNQ_QKQ20_CP093	Prozesswertarchiv	1134.402100	20.10.04 14:53:52.38
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Eintr. X3180	KNQ_QKQ20_PI3182	Prozesswertarchiv	9.930555	20.10.04 14:53:52.38

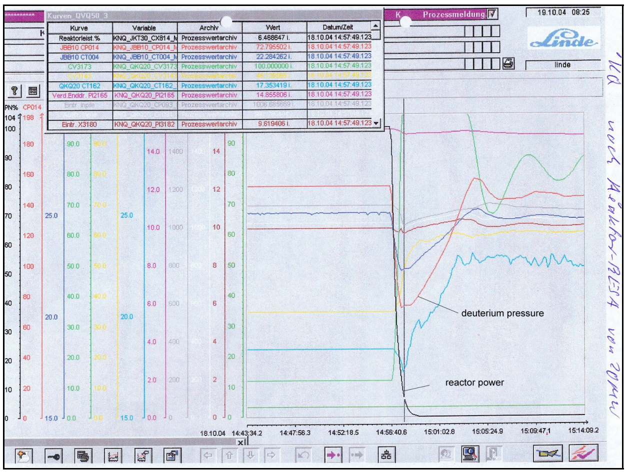
Anlage 1 zu IBS-Ergebnisbericht F4-7
KQ Hochfahren der Reaktorleistung auf 20MW

Reaktorleistung

20MW

0MW

Figure 13 : Fast reactor shut down



Kurve	Variable	Archiv	Wert	Datum/Zeit
Reaktorleist.%	KNQ_JKT30_CX814_M	Prozesswertarchiv	6.468647 i.	18.10.04 14:57:49.123
JBB10 CP014	KNQ_JBB10_CP014_M	Prozesswertarchiv	72.795502 i.	18.10.04 14:57:49.123
JBB10 CT004	KNQ_JBB10_CT004_M	Prozesswertarchiv	22.284262 i.	18.10.04 14:57:49.123
CV3173	KNQ_QKQ20_CV3173	Prozesswertarchiv	100.000000 i.	18.10.04 14:57:49.123
CV3143	KNQ_QKQ20_CV3143	Prozesswertarchiv	48.139565 i.	18.10.04 14:57:49.123
QKQ20 CT162	KNQ_QKQ20_CT162_	Prozesswertarchiv	17.353419 i.	18.10.04 14:57:49.123
Verd.Enddr. PI2165	KNQ_QKQ20_PI2165	Prozesswertarchiv	14.855806 i.	18.10.04 14:57:49.123
Eintr. Inpile	KNQ_QKQ20_CP093	Prozesswertarchiv	1006.685669 i.	18.10.04 14:57:49.123
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Eintr. X3180	KNQ_QKQ20_PI3182	Prozesswertarchiv	9.619406 i.	18.10.04 14:57:49.123

KQ nach Reaktor-RESA von 20MW

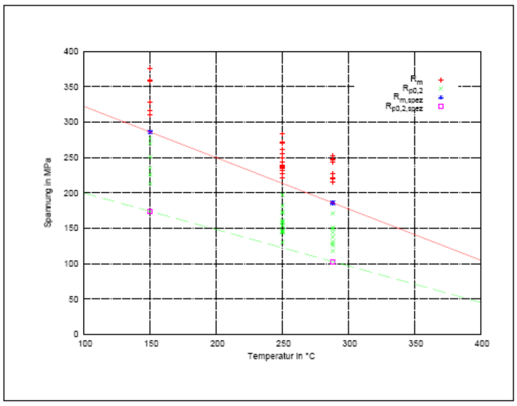
6. Design variation

The following design variation were done for the HNS and CNS. These variation were caused by commissioning results. For the design temperature increase to 300°C for the inner vessel of the HNS additional stress calculations and material investigations were done. The following table shows the material test results of zIrcaloy 4:

sample	thickness	°C	Sample	Rm MPa	Rp0,2 MPa
522	10	300	T	227	152
524	10	300	T	209	139
246	10	300	L	294	159
417	3	300	L	279	176

Figure 14 shows that these results are acceptable and above the specified values.

Figure 14: Material test results of Zircaloy 4



7. Inservice inspection, maintenance and repair

Within the licensing requirements inservice inspection has to be specified. The visual inspection of the inner side of the D2 system are not possible with respect to the Tritium inventory on the inner side. With the licensing authority other inspections -as NDT and control of the I&C measurements- were discussed under consideration of the barrier and safety concept of the CNS and agreed.
One NDT inspection within the inservice inspection program shows a local indication at the helium storage tanks. A sample was taken and investigated, the local areas were repaired.
During the cold commissioning phase a small leak was detected in the heat exchanger of the CNS arranged in the inner side of the inpile part. The heat exchanger was dismantled from the inpile part , the leak was detected and a weld was locally repaired. Both repairs were done sufficient, this shows that the local constructional arrangement of the CNS was designed good.

8. Conclusions

-The cold and hot commissioning of the CNS and HNS has been completed successfully, the specified data were confirmed
-The operational conditions could be changed for optimization of the CNS processes
-The design optimization of the source could be done sufficient from safety point of view under consideration of the commissioning results
-The inservice inspection concept of the CNS was upgraded to take the safety concept into account
-The maintenance and the repair of components could be done sufficient under consideration of the local arrangements
- All variations were in agreement with the licensing authority

9. References

/1/ K. Gobrecht, E. Gutsmiedl, A. Scheuer;
Status report on the cold neutron source of the Garching neutron research facility FRM II, Physica B 311(2002), 148 – 151

/2/ E. Gutsmiedl, H.Posselt, A. Scheuer
Transient analysis for the cold neutron source at FRMII
4. International Workshop UCN and CNS neutron physics and sources, June 16-21, 2003 St.Petersburg, Russia

/3/ E. Gutsmiedl, D. Päthe, K. Zeitelhack, F. Grünauer, A. Scheuer
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5. International Workshop UCN and CNS neutron physics and sources, July 13-18, 2005 St.Petersburg, Russia